

# Worldwide Progress in Vehicle Technology and Emissions Norms Leaders and Laggards Need To Move Fast

March 11, 2015

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# *Automobiles and the Environment*

Global Environment



Urban Environment

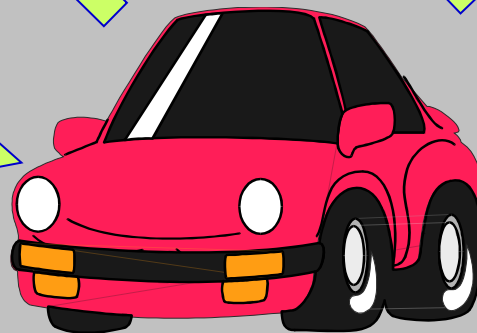


Emissions

CO<sub>2</sub>, BC, O<sub>3</sub>      VOC, NO<sub>x</sub>, PM

Alternative Fuels

Energy  
Security



Recycle

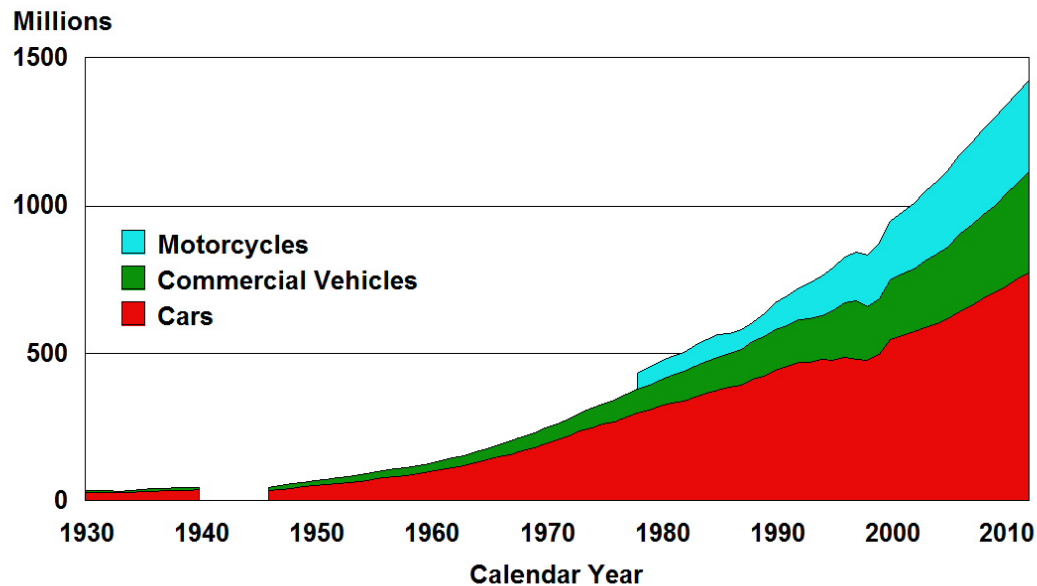
Economy

Safety

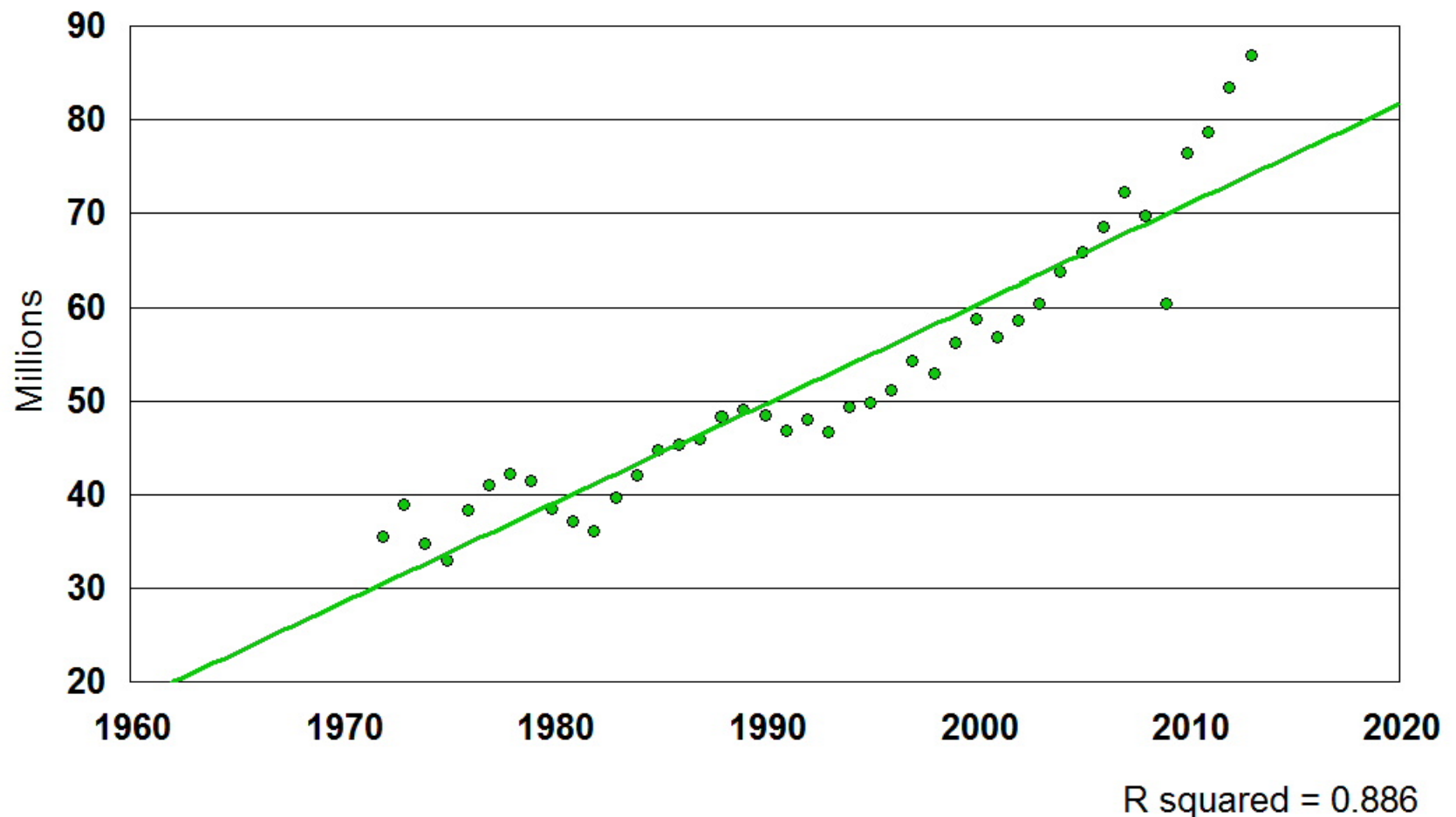
Convenience

# Historical High Growth Has Resulted In Vehicles Being Important Contributor To Local, Regional and Global Pollution

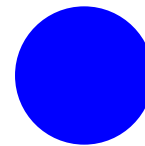
**Figure : World Motor Vehicle Population**



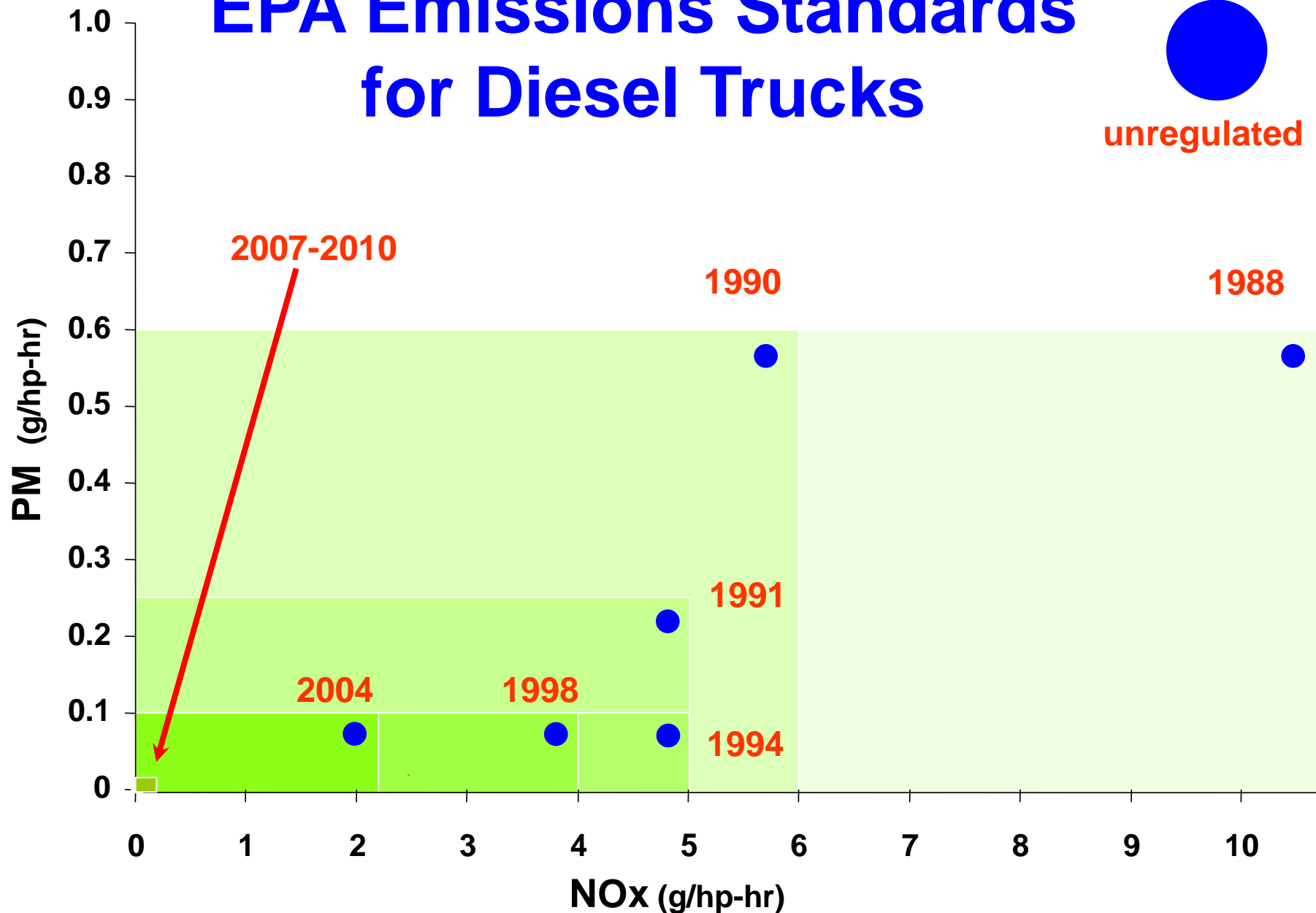
# Figure : Annual Production of Cars, Trucks and Buses



# EPA Emissions Standards for Diesel Trucks



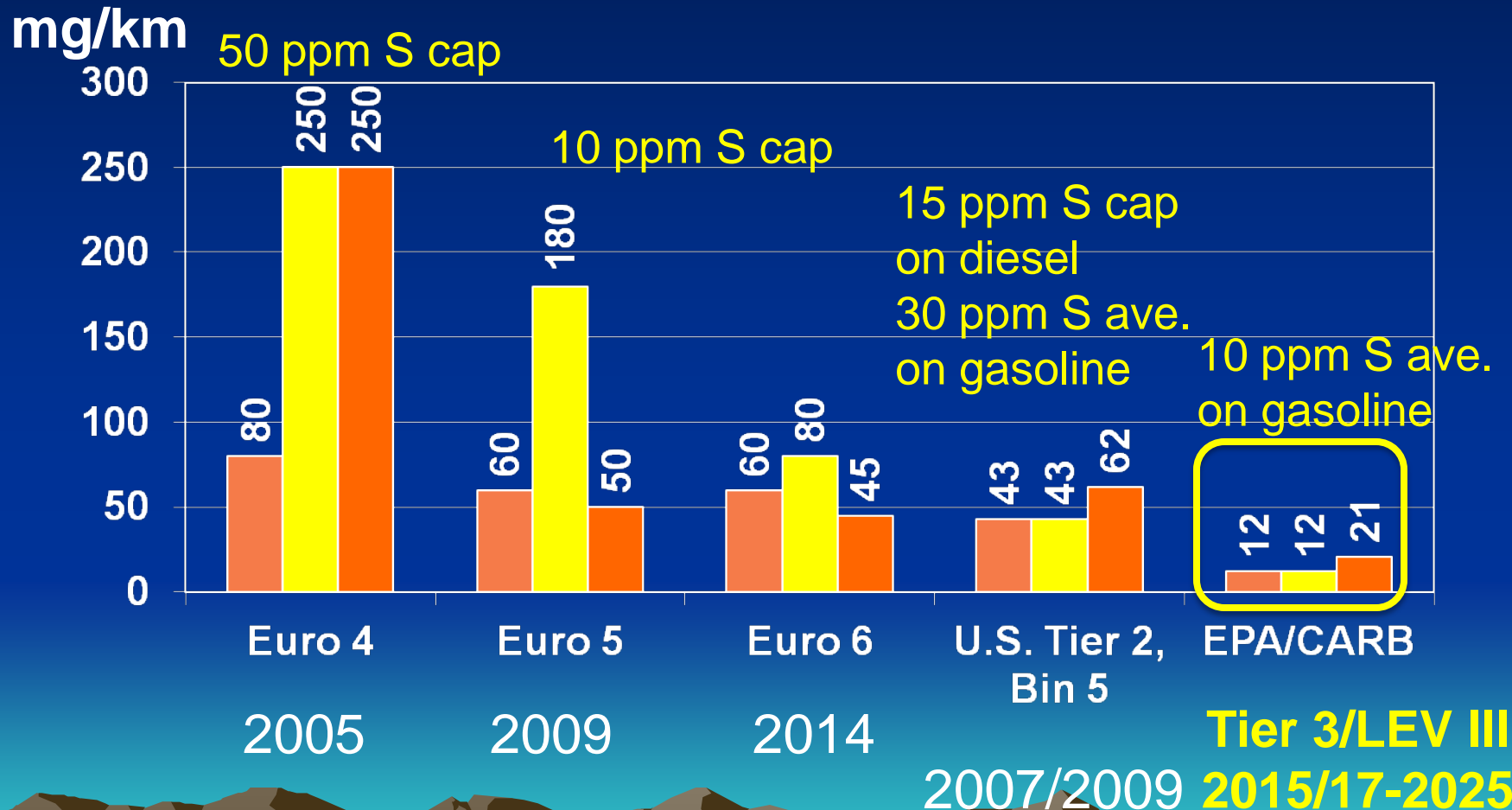
unregulated



# U.S. and Euro Light-Duty Vehicle Emission Standards

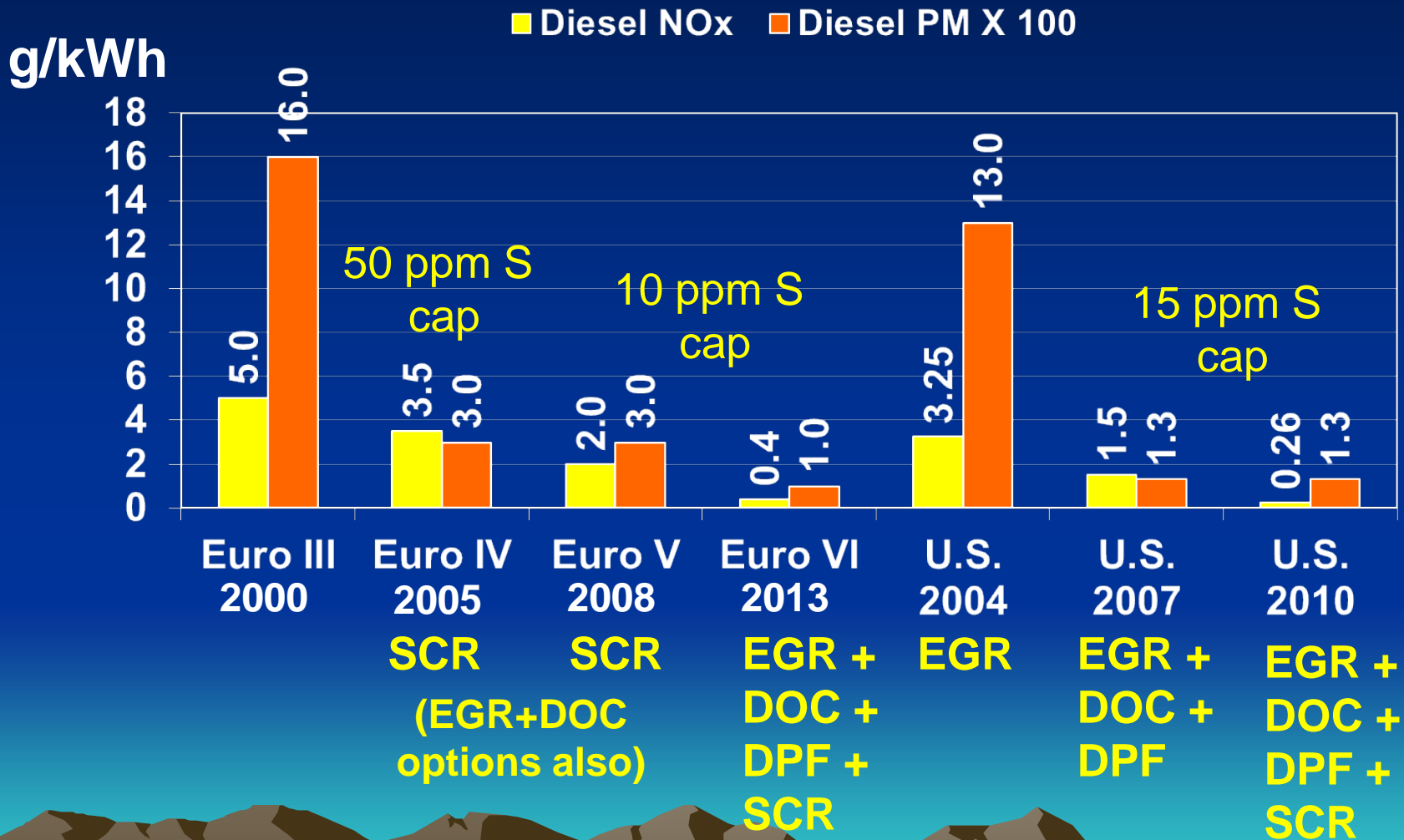
Note: U.S. Tier 2, Bin 5 is equivalent to CARB LEV II - LEV

■ Gasoline NOx ■ Diesel NOx ■ Diesel PM X 10



Euro 5+ (2011) and 6 include  $6 \times 10^{11}$ /km diesel particle number limit;  
Euro 6c includes PN limit for GDI

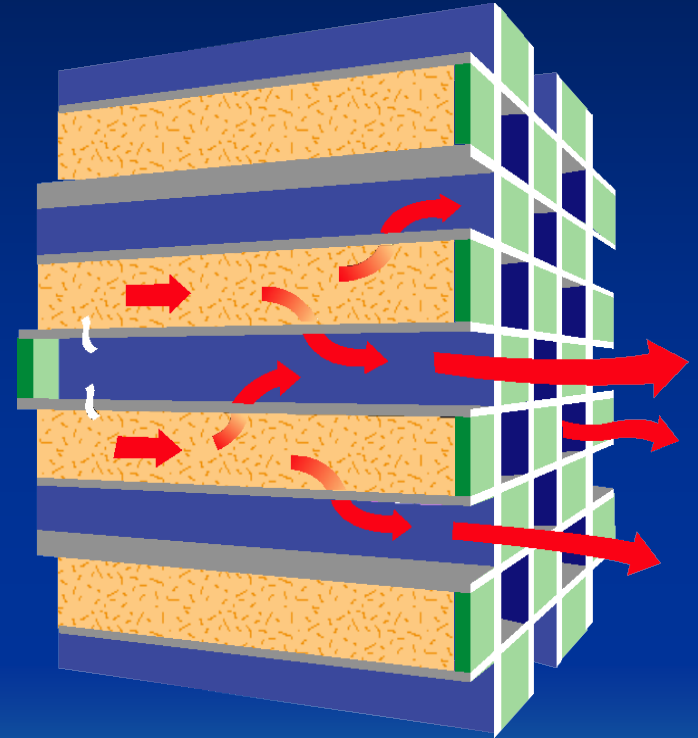
# U.S. and Europe: Heavy-Duty Primary Exhaust Emission Control Technologies





# Diesel Particulate Filters (DPFs)

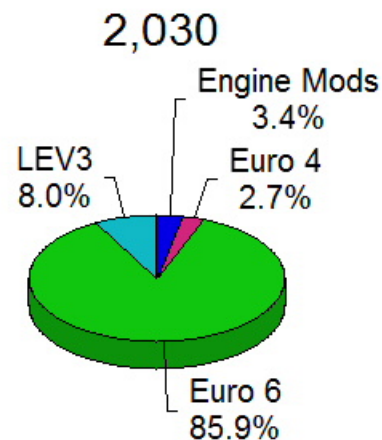
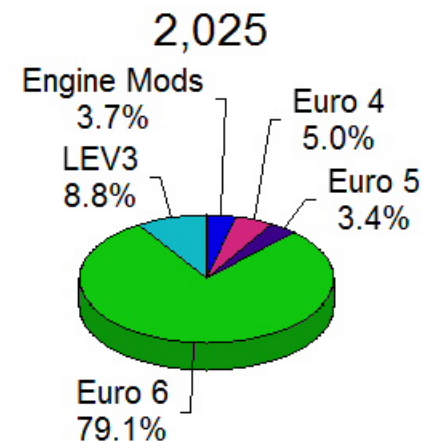
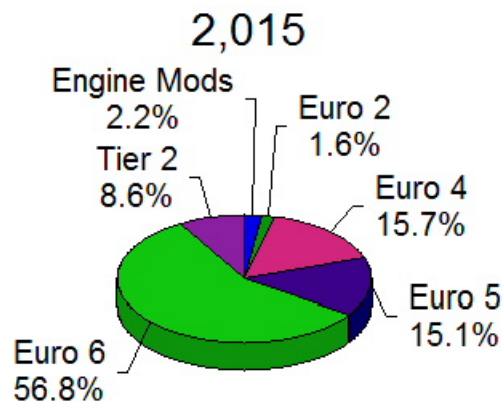
- Wall flow ceramic filter element with high capture efficiency for particulates over a broad size range (cordierite or SiC filter elements)
- Captured soot needs to be burned off (regenerated) at regular intervals to manage backpressure on engine
- Commercialized on light-duty diesels in Europe in 2000, on US LDD starting in 2006; standard on US 2007+ trucks/buses, on 2013+ Euro VI trucks/buses – 10s of millions in-use worldwide
- Capture soot and inorganic-based particles associated with engine wear, lubricant consumption: regular maintenance required (filter cleaning)





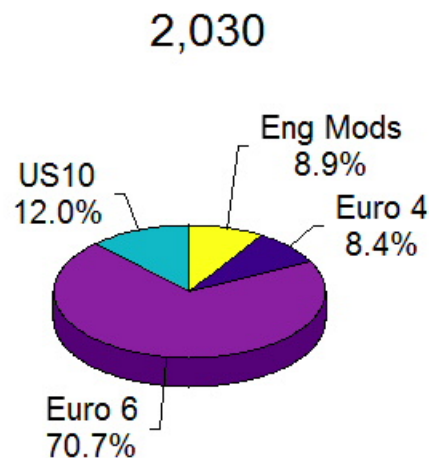
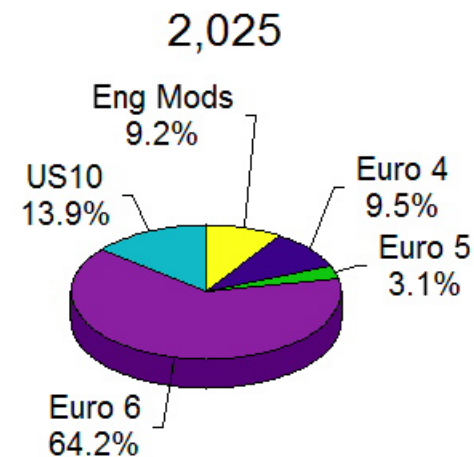
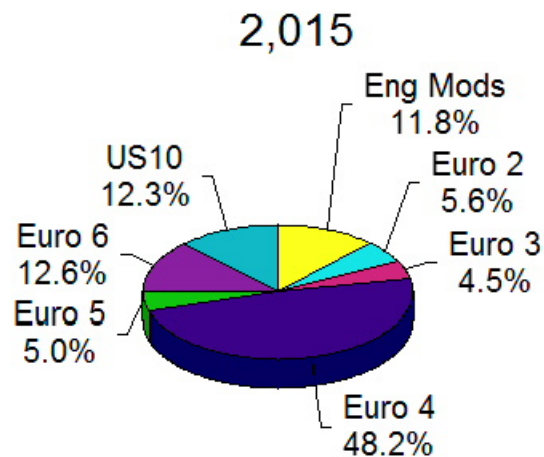
# Distribution of Controls

## Light Duty Diesel Vehicles

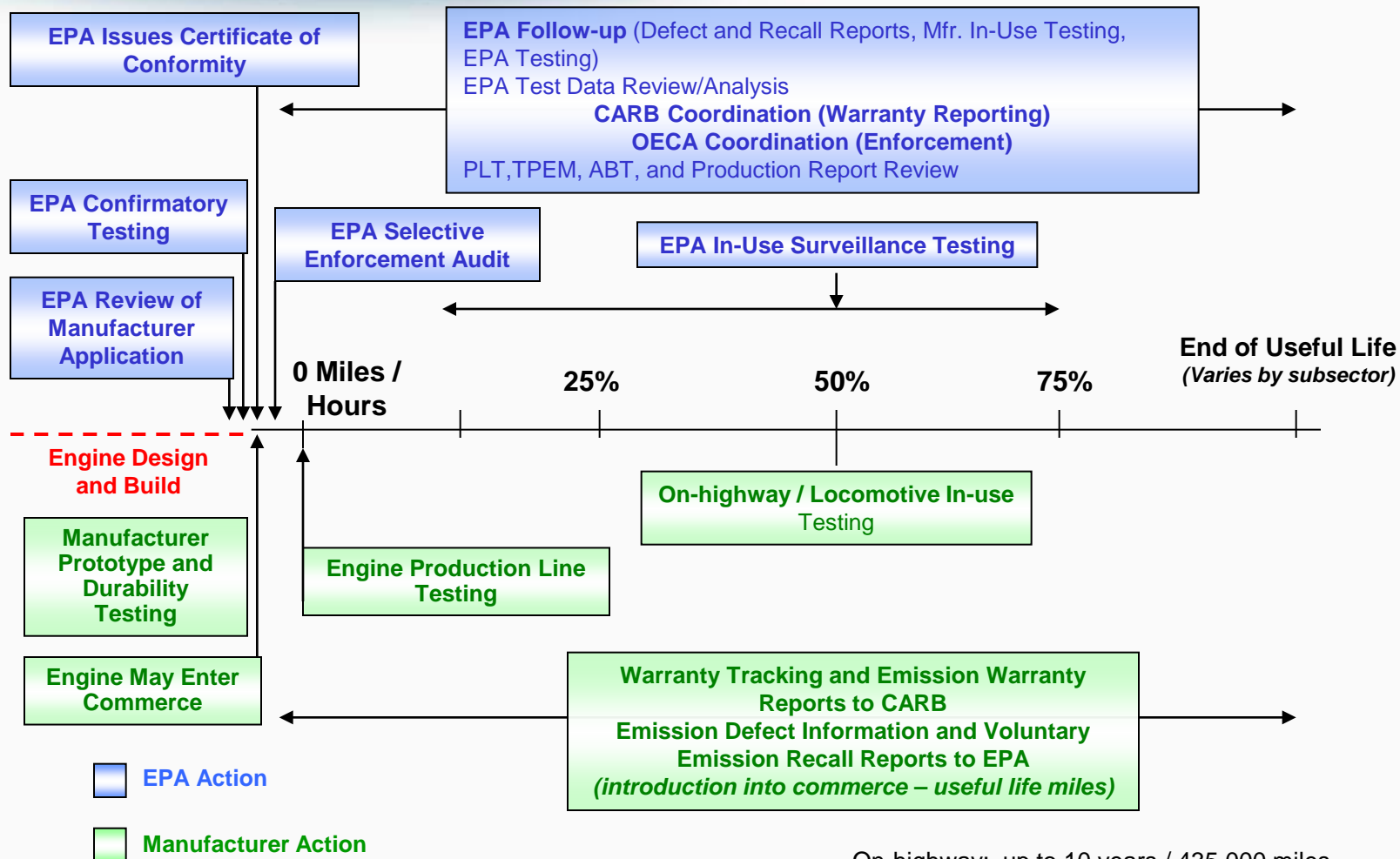


# Distribution of Controls

## Heavy Duty Diesel Vehicles



# Diesel Engine Compliance Program



Full Useful Life:

On-highway: up to 10 years / 435,000 miles

Nonroad: up to 10 years / 8,000 hours

Marine: up to 10 years / 20,000 hours

Locomotive: up to 10 years / 32,000 MW-hours

# Clean Diesel Vehicles Include Sophisticated Sensors and Diagnostics



Combined O<sub>2</sub>/NO<sub>x</sub> Sensor



Ammonia Sensor



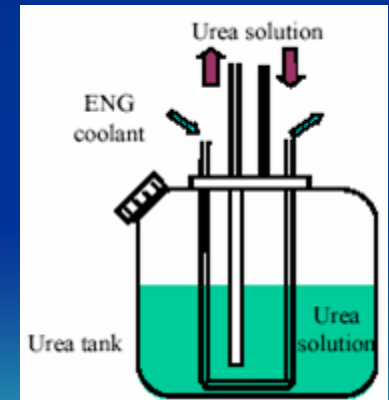
Soot Sensor



Urea Quality Sensor



Diagnostic Systems



Heated Urea Tanks

# U.S. 2007 HD Emission Performance Provides Significant Reductions in PM, CO, Air Toxic HCs

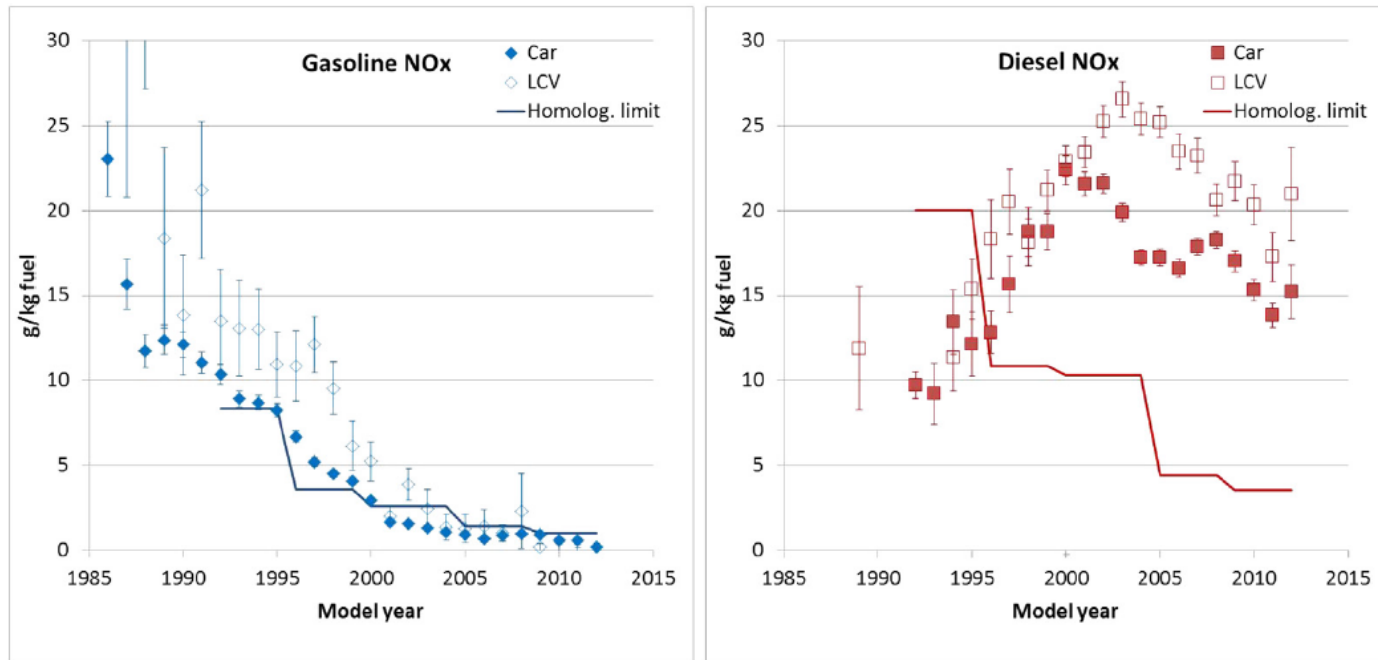
	2007 EPA Standard (g/hp-hr)	Average ACES Engine Emissions (g/hp-hr)	ACES Emissions % Reduction Relative to the 2007 Certification Standard
CO	15.5	0.33	98
NMHC	0.14	0.0064	95
PM	0.01	0.0011	89
NO <sub>x</sub>	1.2 <sup>a</sup>	1.075	10
<sup>a</sup> Average value between 2007 and 2009, with full enforcement in 2010 at 0.20 g/hp-hr			

Compounds	% Lower Than 2004 Engine Technology	
	16-Hour Cycle	CARBx-ICT
Single Ring Aromatics	82%	69%
PAH	79%	26%
Nitro-PAH	81%	49%
Alkanes	85%	84%
Polar	81%	12%
Hopanes/Steranes	99%	99%
Carbonyls	98%	78%
Inorganic Ions	38%	100%
Metals and Elements	98%	90%
Organic Carbon	96%	78%
Elemental Carbon	99%	100%
Dioxins/Furans <sup>a</sup>	99%	N/A
<sup>a</sup> Relative to 1998 Engine Technology		

Source: CRC Phase 1 ACES Report;  
2010+ Engines Delivering Even Lower  
Toxic HC Emissions than 2007 Engines



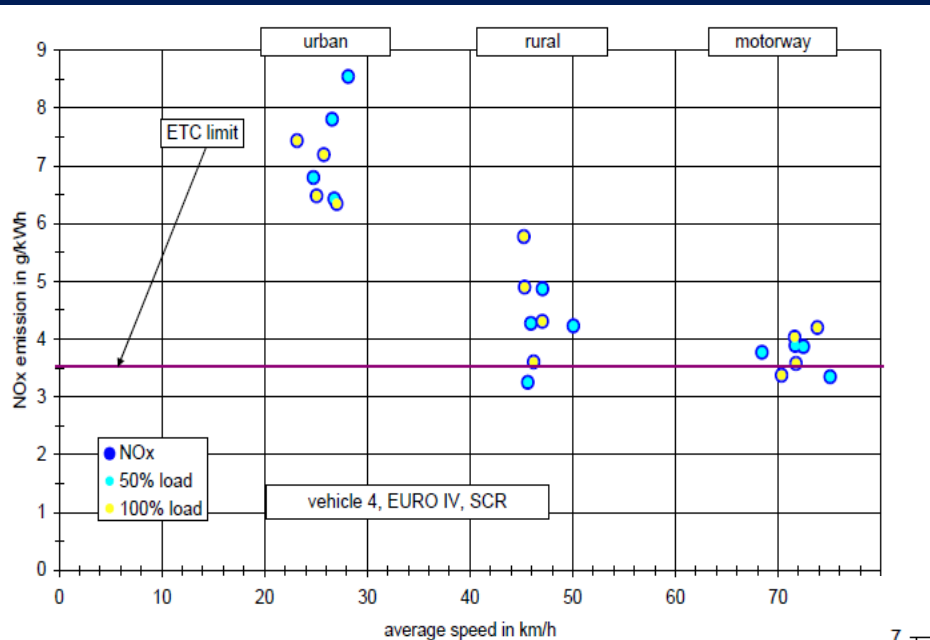
# Developments for Euro 1 – Euro 5



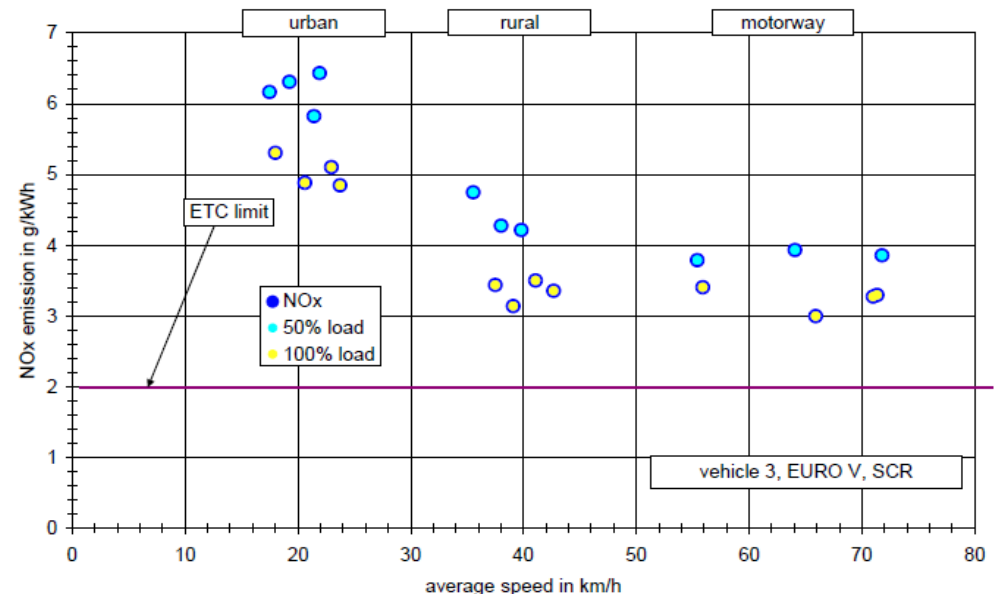
**Fig. 4.** Mean hot NO<sub>x</sub> emission factors of gasoline (left) and diesel (right) passenger cars and light commercial vehicles as a function of model year. Whiskers represent the 95% confidence interval over the mean. Added are the type approval limit values for Euro 1 to Euro 5 passenger cars over the homologation test cycle in force in the respective year. For conversion from limit values in g per km see SI (using measured fuel consumption rates from [Hausberger \(2010\)](#)). For color plot consult online version.

# What About Trucks?

The problem: High off-cycle NO<sub>x</sub> emissions in urban applications



In-use PEMS testing of Euro IV and Euro V trucks in The Netherlands found emission well above standard in urban driving in 2008!

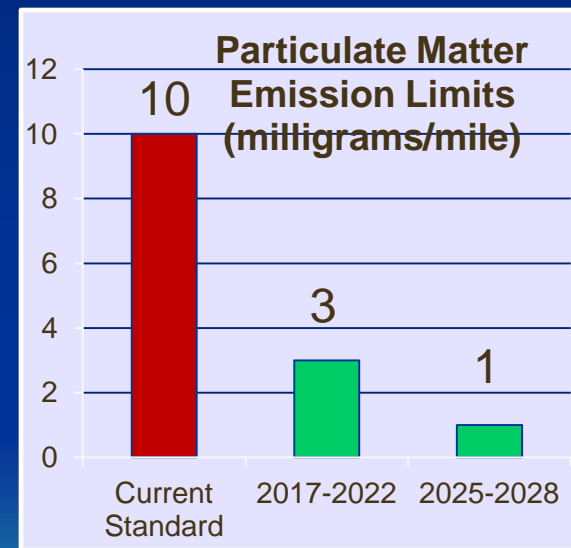
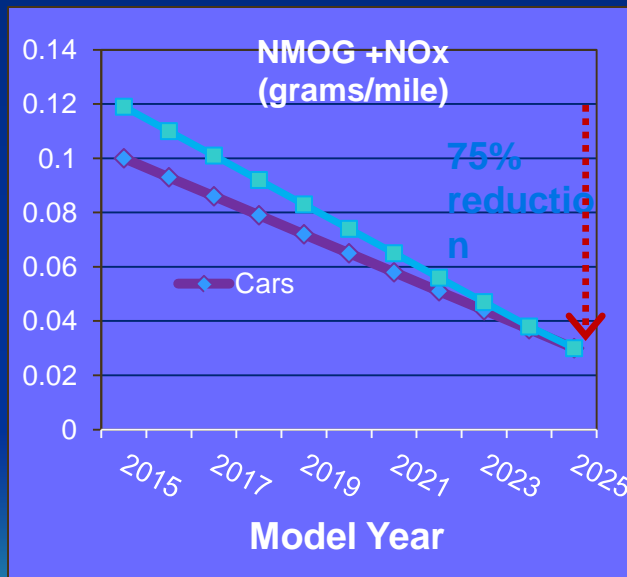


Source: Kleinebrahm 2008



# California's Low-Emission Vehicle Program

- Adopted in 2012
- Achieves 75% reduction in smog-forming pollution
- Achieves 90% reduction in PM standard

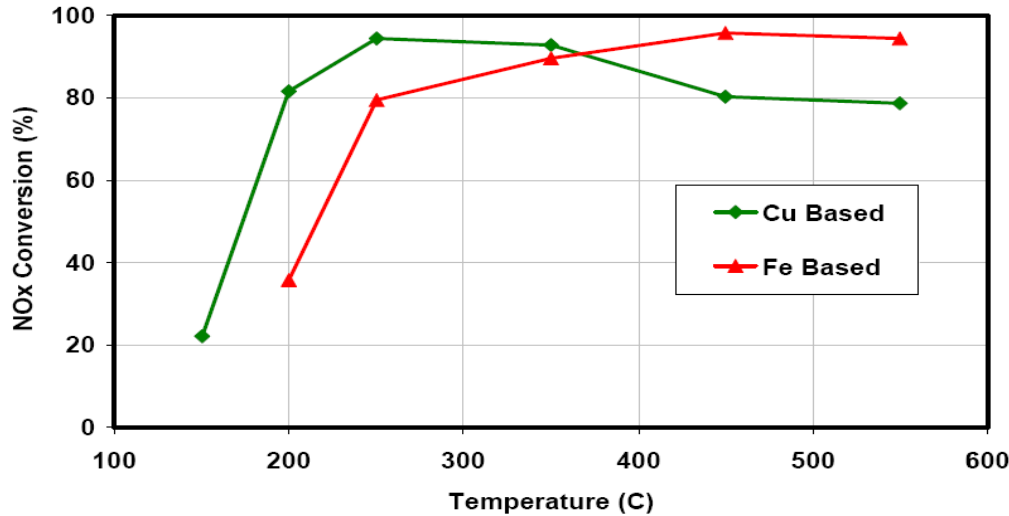


# Proposed Optional Low NOx Engine Emission Standards for MY 2015+

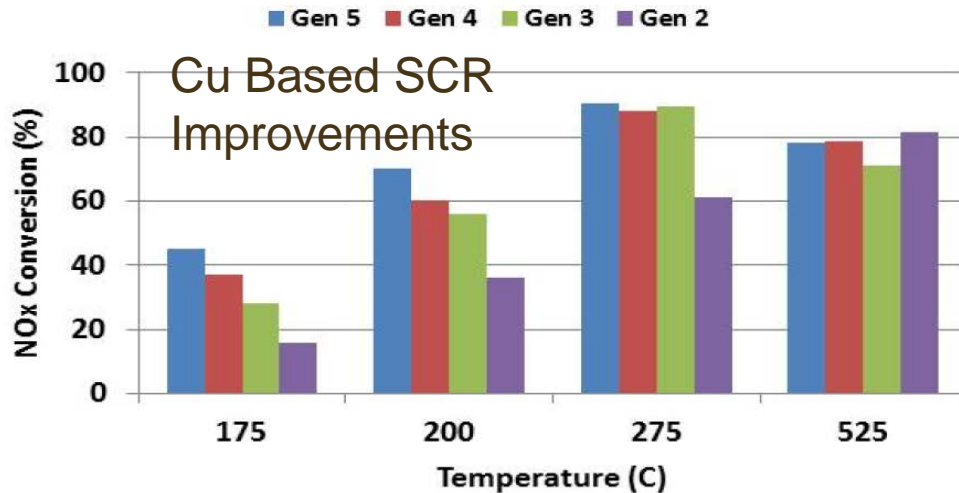
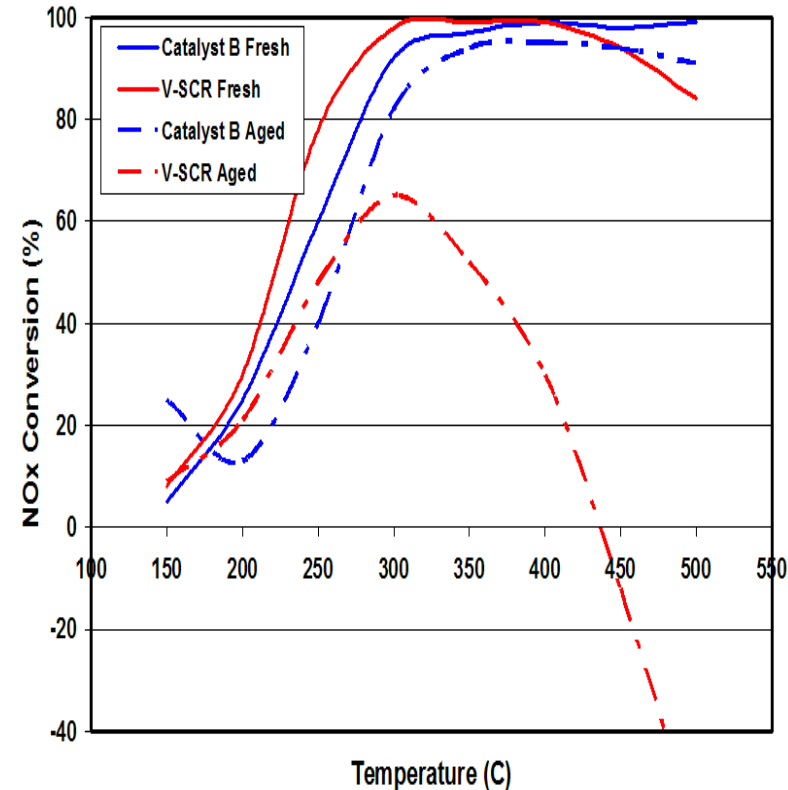
NOx Level g/bhp-hr	% Below Current Standard
0.2 (Current)	
0.1	- 50%
0.05	- 75%
0.02	- 90%

# Zeolite SCR Catalysts Developed for Mobile Source Applications with Broad Temperature Windows and Good Thermal Stability

SV=30K/hr, NO=350ppm, NH<sub>3</sub>=350ppm, Aging =670C/64h



Aged 650°C, 100 Hours; Tested at 100k SV



SCR catalysts aged  
50 hours at 700C

# Clean Diesel Technology Driven By a Decade of U.S. EPA Mobile Source Emission Regulations

Average Benefit:Cost = 20:1

## Tier 2 Light-Duty

final rule 1999

fully phased in 2009

Diesels held to same standards as  
gasoline vehicles

**Diesel sulfur now 15 ppm**



## Ocean-going Vessels

final rule 2009; IMO ECA in 2010

**ECA: 1000 ppm Sulfur in 2015;  
80% lower NOx by 2016**



## Heavy-Duty Highway

final rule 2000

**Sulfur now 15 ppm**

fully phased in 2007-2010



## Nonroad Diesel Tier 4

final rule 2004

**Sulfur now 15 ppm**

fully phased in 2015

## Locomotive / Marine Tier 4

final rule 2008

**Sulfur now 15 ppm**

fully phased in 2017

# Significant On-Road Retrofit Experience, Off-Road Experience Growing

- >300,000 on-road DPF retrofits and >50,000 off-road DPF retrofits worldwide; > 100,000 DPF retrofits in the U.S.
- >1 million DOC retrofits worldwide
- Significant experience with retrofit technologies exists for on-road vehicles
  - School buses, transit buses, long- and short-haul trucks, refuse haulers, utility vehicles
- Retrofit experience is growing for many off-road applications
  - Construction equipment
  - Port vehicles/equipment
  - Marine engines and locomotives
  - Stationary internal combustion engines used for power generation



# Technical Considerations for Successful Retrofit Projects

- Vehicle should be properly maintained before considering retrofit
- Application engineering – Matching the right technology to the specific piece of equipment and application
- Proper professional installation – Retrofits can be installed safely (visibility concerns addressed)
- On-vehicle monitors – Provide important user feedback on performance (don't ignore warning lights)
- Maintenance – Vehicle/equipment and retrofit device require inspection and maintenance

Successful Retrofits Require a Cooperative Effort Between Fleet Owners, Operators, and Technology Providers

## **India covered a lot of ground from 2001-2010, but is falling behind now**

- For 2/3 wheelers:
  - HC+NOx combined standards;
  - Poor durability
  - No evaporative emission standards
- For Light-Duty Vehicles:
  - Diesel car share has increased to 50% of new vehicle sales in FY 2012-2013
    - Euro IV diesels emit three times NOx and an order of magnitude higher PM emissions than Euro IV petrol
  - Little progress on refueling evaporative emissions
- For Commercial Vehicles and Buses:
  - BS IV limited to a few bus fleets, trucks still at BS III



# Auto Fuels Policy Committee Vision

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- Fuels Road Map
  - BS IV Fuels (50 PPM) Phased in Across Entire Country by 1 April 2017
  - BS V Fuels (10 PPM) Phased in Across Entire Country by 1 April 2020
- Vehicle Emissions Road Map
  - BS IV Nationwide in 2017
  - BS V for New Models from 1 April 2020 and all Models by March 31 2021
  - BS VI Four Years after BS V (1 April 2024)

# Our Recommendations

- Enhance and then Adopt Recommendations From Committee on Auto Fuel Vision and Policy
  - Skip Euro 5/V and go directly to Euro 6/VI
  - Add ORVR and Zero Evaporative Emissions.
- Replace current test cycles with world-harmonized test cycles for all vehicle types.
- Ministry of Petroleum and Natural Gas should establish national fuel testing program at retail outlets
- Ministry of Road Transport and Highways should establish national in-use vehicle testing

# Advantages of Euro 6/VI Over Euro 5/IV

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- Tighter Standards
- New and Improved Test Procedures Provide More Comprehensive Coverage of Range of Real World Driving Conditions
- Actual In Use Focus (RDE)
- Improved Onboard Diagnostics
- Likely Gasoline Particle Filter

Thank You

